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Citation for published version:

Olkis, C, Brandani, S & Santori, G 2019, 'A small scale adsorption desalinators', *Energy Procedia*, vol. 158, pp. 1425-1430. <https://doi.org/10.1016/j.egypro.2019.01.345>

Digital Object Identifier (DOI):

[10.1016/j.egypro.2019.01.345](https://doi.org/10.1016/j.egypro.2019.01.345)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Publisher's PDF, also known as Version of record

Published In:

Energy Procedia

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10th International Conference on Applied Energy (ICAE2018), 22-25 August 2018, Hong Kong, China

A small-scale adsorption desalinators

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Abstract

Adsorption desalinators produce potable water from seawater by utilising low-grade heat 50-90 °C. Experimental systems were introduced in a number of studies and proved the feasibility of the concept. However, the proposed experimental systems have large bed sizes of up to 36 kg, which leads to an inflexibility in their operation and the change of components. Here we introduce a novel, small-scale adsorption desalinator, which is currently the world's smallest with a bed size of 0.2 kg. The small scale will enable us to test advanced, non-commercial adsorption materials, which are not available in large quantities yet. Moreover, different component designs will be assessed to optimise the performance. The starting point of the investigation will be a series of experiments with Siogel silica gel. The results represent a benchmark case for further investigations, provide compelling insight into the process, and contribute to the advancement of temperature swing adsorption.

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Peer-review under responsibility of the scientific committee of ICAE2018 – The 10th International Conference on Applied Energy.

Keywords: Desalination, Adsorption, Silica Gel, Low-grade heat

1. Introduction

Two-thirds of the world population are already facing severe water scarcity for one month each year [1], while climate change and a growing world population can only worsen the situation in the future. Consequently, much research has focused on sea water desalination. Recently, adsorption desalination was proposed as a novel, thermal desalination method arising as a further development of adsorption heat pumps [2] and has generated considerable research interest [3,4]. Another promising application of thermal desalination methods is their combination with a Reverse Electrodialysis membrane [5] to generate electricity from low-grade heat sources, where adsorption desalination can also be employed [6].

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Adsorption desalinators utilise low-grade heat sources as low as 50 °C, where the exergetic content of the heat source described through the Carnot factor is only 8%. Heat sources at this temperature level are available in abundance [7], but only very few technologies are available to utilise them, which is why adsorption desalination is a very promising application.

In recent years researchers have studied and built experimental adsorption desalinators, while focusing on the system performance: Maximising the water production and minimising the energy input.

However, the proposed prototypes are usually very large with bed sizes of up to 36 kg [3]. On the one hand, the scale of these systems has the advantage of being closer to an industrial application. On the other hand, the large scale leads to an inflexibility of the system, because the change of the material, the heat exchangers, or other components is costly and more difficult.

In the present study we introduce a novel, small-scale adsorption desalinator. The small-scale prototype is currently the world's smallest design and distinguishes itself from previous systems through two novel aspects:

- The small scale: Compared to other systems, the bed size is reduced by two orders of magnitude to 0.2 kg. The small scale simplifies the testing of different adsorption materials and reduces the total energy consumption of the system. Further benefits of the small-scale are the minimal lab space requirements and the utilisation of a small heat source like standard thermostatic baths.
- The modular design: All system components are easily interchangeable to facilitate the optimisation of the system and the process.

2. The prototype and process design

The adsorption desalinator is designed to utilize low-grade heat between 50-90 °C and the system consists of four vacuum vessels: Two adsorbers are connected to an evaporator as well as a condenser as it can be seen in the centre of Fig. 1 (left). Each one of the vessels is equipped with a heat exchanger, a pressure transducer and thermocouples. Two water loops simplify the piping of the system [4] and supply water from the thermostatic baths to the heat exchangers. The thermostatic baths provide heating/cooling water at three different temperature levels: cold, ambient and hot. Typically, much larger heat sources are required to supply the beds of adsorption desalinators. Whereas, regular thermostatic baths are sufficient to heat and cool the 0.2 kg of silica gel inside each bed of the novel desalination prototype.

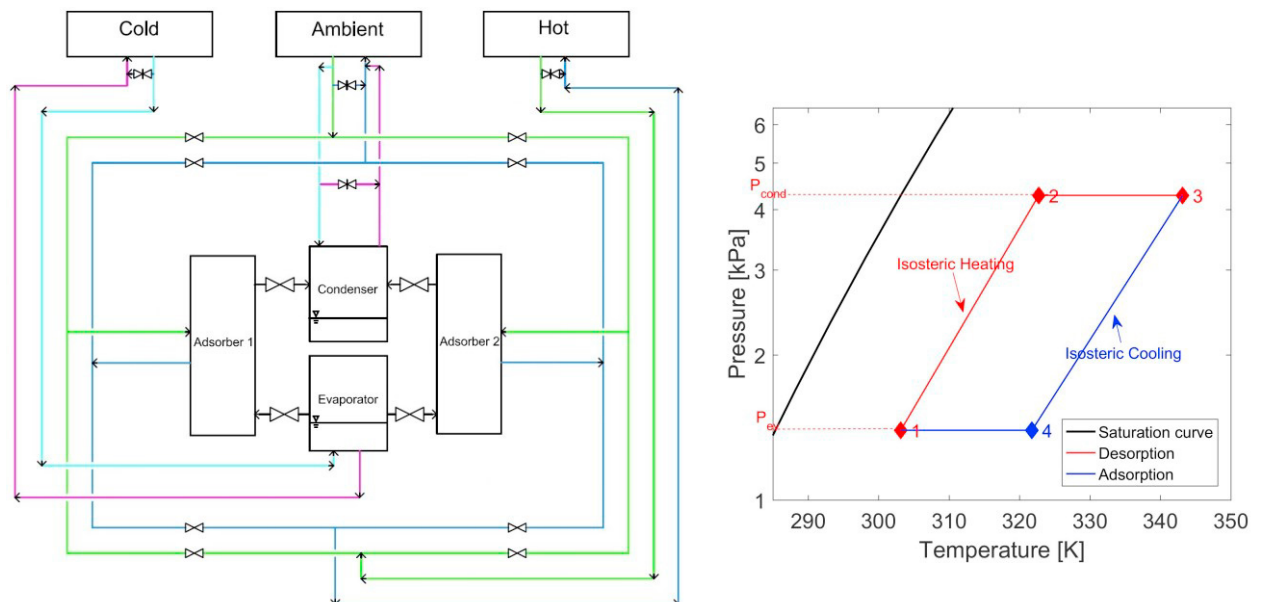


Figure 1: The flow diagram of the adsorption test rig (left) and the ideal adsorption cycle each one of the beds undergoes (right)

Each one of the beds undergoes cyclic heating and cooling to perform the adsorption cycle shown Fig. 1 (right). During the desorption step, the cold, saturated bed is heated and disconnected from evaporator and condenser, which is called isosteric heating. The pressure of the bed increases until it reaches the condenser pressure. Now, the bed is connected to the condenser and water vapour desorbs from the silica gel and condenses on the cold surface of the condenser heat exchanger. Once the bed is regenerated, the valve connecting condenser and evaporator is closed and the bed is cooled to decrease the pressure again, called isosteric cooling. When the pressures of the adsorber bed and evaporator are equal, the valve between the two vessels is opened. As a result, the silica gel bed adsorbs water vapour from the evaporator, which is partially filled with water. A semi-continuous mode of the test rig is ensured by regenerating one bed, while the other bed adsorbs.

A two-dimensional drawing of the test rig is shown in Fig. 2, which illustrates the small size of the system. The height of the system is less than 500 mm, the width and length are less than 300 mm. This small-scale, modular design allows a higher flexibility in changing components, adsorption materials and fluids. The system consists of four 316L stainless steel vessels, which are the evaporator, two adsorber vessels and the condenser. Inside each one of the vessels is an aluminium heat exchanger connected to the heating and cooling water system. Moreover, each one of the vessels is equipped with ISO-KF flanges and is mutually connected through electro-pneumatic valves (Pfeiffer Vacuum GmbH, Germany). A pressure transducer is fitted on each vessel (WIKA Alexander Wiegand SE & Co. KG, Germany, 0.25 % accuracy). Both, the evaporator and the condenser feature viewports (Pfeiffer, Germany) to check the water level and the formation of vapour bubbles during evaporation. The evaporator and condenser are equipped with T-Type thermocouples (Omega Engineering, USA, 0.4 % accuracy), which measure the temperatures of the vapour and liquid phases. Additional thermocouples are placed at the outlet and inlet to the heat exchangers of all four vessels. These thermocouples are used to determine the temperature difference of the heating and cooling water supplied to the heat exchangers.

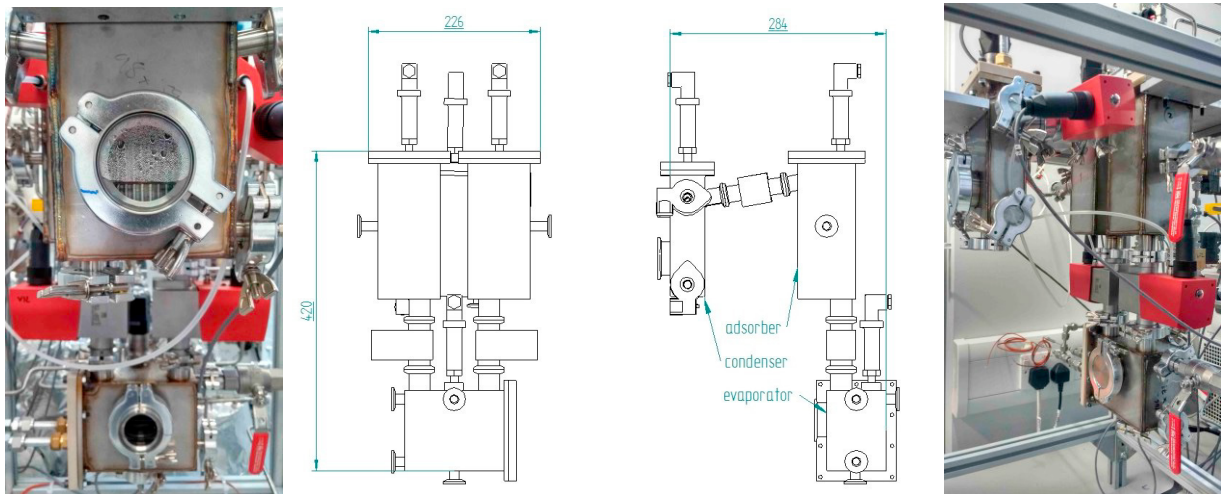


Figure 2: Left: Front view of adsorption test rig during experiment. Middle: 2-D SolidEdge drawing of the system including dimensions. Right: Side view of the adsorption test rig.

2.1 The adsorber beds

The aluminium heat exchangers placed inside the adsorber vessels are presented in Fig. 3 (RC Racing Radiators, Italy). The space between the fins of the heat exchanger is 5 mm and it is filled with micro-porous beads of silica gel (Siogel Oker-Chemie GmbH, Germany), which have a diameter of 0.5-2.0 mm. Siogel silica gel [8] is a newer adsorption material with similar properties to Fuji Davison silica gel RD [9], which is commonly used in adsorption

desalination, but is discontinued. The silica gel beads are secured inside the heat exchanger with a 290 μm polymer mesh (Plastok Meshes & Filtration Ltd, UK) with an open area of 50 %. Each heat exchanger has a weight of 600 g and is filled with 210 g of silica gel resulting in a material to adsorbent weight ratio of about 3 to 1.



Figure 3: The heat exchangers packed with silica gel

The overall system fits on a workbench of 2 m length and 1 m width (Fig. 4). On the left side of the bench, the frame with the adsorption test rig is placed. In the middle, the heating and cooling water pipes are located with the rotameters (Nixon Flowmeters, UK, 1.6 % accuracy), which are needed to determine the water flow rate supplied to each one of the heat exchangers. The heating and cooling water cycle is connected to the thermostatic baths (Julabo, Germany), which is an advantageous feature of the system. Usually the energy requirements of adsorption desalinators are vast and exceed the heating/cooling capacity of a thermostatic bath by far. Furthermore, the internal pumps of the thermostatic baths are sufficient to supply water to the heating/cooling cycle.



Figure 4: The experimental adsorption test rig with all system components

The pressure and temperature sensors are directly connected to a data acquisition and control board (Advantech Co. Ltd., USA), which is monitored on a PC by a control code based on Labview software (National Instruments Corp., USA). The Labview code was specifically designed and customised for the test rig. The code allows the adjustment of the cycle times and the manual input of the flow rates as they are set only once at the beginning of the experiment and remain the same throughout the entire experiment. Whereas, the readings of the thermocouples and pressure

transducers change constantly and are acquired by the data acquisition and control board, which also actuates the solenoid and electro-pneumatic valves.

3. Experimental Work

Fig. 5 shows the temperatures measured at the outlets of each heat exchanger during an exemplary experimental run of the test rig. It can be seen that the two adsorber beds undergo cyclic heating and cooling, where the hot bed desorbs water vapour to the condenser, while the cold bed adsorbs water vapour from the evaporator. By contrast, evaporator and condenser remain at a constant temperature level. Different temperature levels in each vessel can be adjusted through the thermostatic baths. The temperature levels have a significant impact on the system performance and the water uptake of the material. Another important system parameter is the cycle time as there is a trade-off between fast cycles and longer cycles. The water uptake increases over time until saturation, while the rate of adsorption decreases over time. In addition, faster cycles increase the energy consumption as the mass of the heat exchangers has to be heated and cooled as well during each cycle.

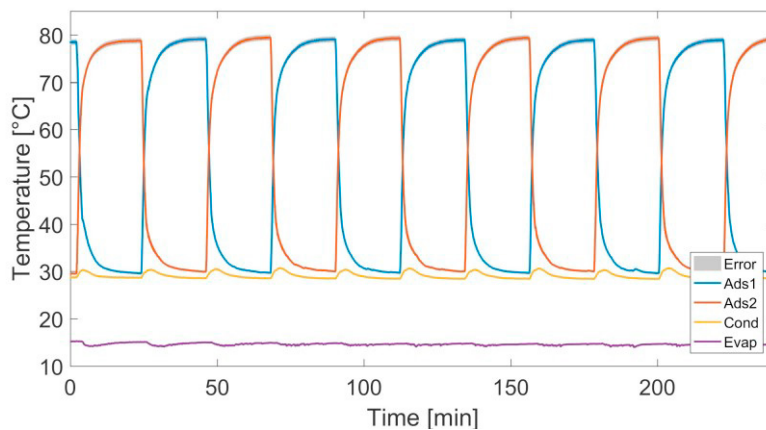


Figure 5: The temperature curves obtained during an experiment

The temperature readings can be used to calculate the water production inside the condenser through energy balances regarding the temperature differences between the inlet and outlet of the heat exchangers. The energy analysis determines the heat and mass flows inside the system like the water production of the condenser in Fig 6. Several performance indicators can be derived based on this analysis like the performance ratio, the specific daily water production and the specific cooling capacity.

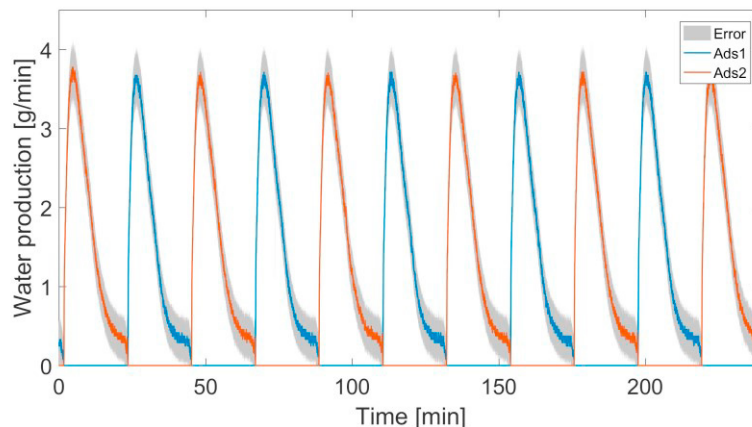


Figure 6: The water production calculated from experimental results

4. Conclusion

A novel, small-scale adsorption desalination prototype was designed, assembled and is introduced here. The test rig is currently the world's smallest design. The small-scale design allows an increased flexibility in testing new materials and system components compared to larger system designs. The novel adsorption desalinator contributes to establishing optimal operational parameters, improving the design of system components and testing advanced adsorption materials. In addition, the experimental investigation will help to gain a better understanding of temperature swing adsorption systems. As adsorption desalination can also be used in combination with a Reverse Electrodialysis membrane to generate electricity from low-grade heat, the experimental results will also be crucial to further develop this concept. The first part of the experimental investigation assesses the performance of Siogel silica gel packed inside the aluminium heat exchangers without heat integration. This starting point establishes a reference case. Further investigations will test other system configurations, which will include heat integration and new heat exchanger designs. Lighter heat exchangers with a better weight ratio hold promise in reducing the energy consumption. Another promising direction will be the testing of novel adsorption materials which will improve both, the energy consumption and the water production. The optimisation process will ultimately contribute to the development of a new generation of refined, advanced adsorption desalinators.

5. Funding

This work was supported by the RED-Heat-to-Power project (Conversion of Low Grade Heat to Power through closed loop Reverse Electrodialysis) - Horizon 2020 programme, Project Number: 640667: www.red-heat-to-power.eu

6. References

- [1] Mekonnen MM, Hoekstra AY. Four billion people facing severe water scarcity. *Science advances*. 2016 Feb 1;2(2):e1500323.
- [2] Freni A, Maggio G, Vasta S, Santori G, Polonara F, Restuccia G. Optimization of a solar-powered adsorptive ice-maker by a mathematical method. *Solar Energy*. 2008 Nov 1;82(11):965-76.
- [3] Ng KC, Thu K, Kim Y, Chakraborty A, Amy G. Adsorption desalination: an emerging low-cost thermal desalination method. *Desalination*. 2013 Jan 2;308:161-79.
- [4] Santori G, Sapienza A, Freni A. A dynamic multi-level model for adsorptive solar cooling. *Renewable energy*. 2012 Jul 1;43:301-12.
- [5] Tamburini A, Tedesco M, Cipollina A, Micale G, Ciofalo M, Papapetrou M, Van Baak W, Piacentino A. Reverse electrodialysis heat engine for sustainable power production. *Applied Energy*. 2017 Nov 15;206:1334-53.
- [6] Olkis C, Santori G, Brandani S. An Adsorption Reverse Electrodialysis system for the generation of electricity from low-grade heat. Submitted
- [7] Papapetrou M, Kosmadakis G, Cipollina A, La Commare U, Micale G. Industrial waste heat: Estimation of the technically available resource in the EU per industrial sector, temperature level and country. *Applied Thermal Engineering*. 2018 Apr 9.
- [8] Santori G, Frazzica A, Freni A, Galièni M, Bonaccorsi L, Polonara F, Restuccia G. Optimization and testing on an adsorption dishwasher. *Energy*. 2013 Feb 1;50:170-6.
- [9] Sapienza A, Velte A, Gírník I, Frazzica A, Földner G, Schnabel L, Aristov Y. "Water-Silica Siogel" working pair for adsorption chillers: Adsorption equilibrium and dynamics. *Renewable Energy*. 2017 Sep 1;110:40-6.